SFRA Test Method Application for Turbo Generator Rotor Winding

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Abstract. The development of technology in the present makes the testing method for analysis to know the defect to insulation winding in rotating machines is varied. There are many specific testing tools to determine the damage. The authors of this paper conduct a preliminary study using sweep frequency response analysis (SFRA) to detect and find damage in the turbo generator rotor winding. SFRA is a test equipment performed on transformers based on the working principle of RLC which are Resistive, Inductive, and Capacitive. The importance of the damage identification process is needed to maintain reliable rotor generator and avoid catastrophic defect to equipment and losses to power plant. In one case study, the rotor generator experienced high vibration indication when operating in high reactive power and the SFRA test results on the rotor winding shows a mismatch between two curves. In another case, a mismatch of SFRA result showed winding deformation, such as coil elongation, without high vibration indication in rotor generator. After inspection, repair, measurement and testing, the SFRA method proves that it can show indications of defect without major dismantling.

1. Introduction

A generator is a device that convert the kinetic energy into electrical energy. There are two type of mechanical parts in a generator, stationary (stator) and rotating (rotor) parts. The rotor generator is the main equipment in a generator that must be maintained to sustain its reliability, which is why proper and accurate maintenance is required. Faulty rotor winding will takes a lot of time to repair and may cause loss of electricity generation. Sweep frequency response analysis (SFRA) is a tool for determining the mechanical integrity of core, winding and clamping frameworks within power transformers by analyzing their electrical transfer functions over a broad frequency spectrum [1]. SFRA is one of the common testing methods for transformer winding [2]. It is also used in analysis of rotating machine equipment such as rotor generator. At the time of maintenance, such as pull out and repair, there is an opportunity to observe the simulation taking defect on the rotor turbo generator. This diagnostic method able to detect and identify two major failures in the rotating motors, which are short circuit between layer coil, and short to ground [3]. Therefore, it is necessary to include this test method analysis in every periodic maintenance.

2. Literature Review

Principally, SFRA technique is based on analyzing the winding impedance in the frequency domain. Since a rotor winding can be modeled as an equivalent circuit with a complex network of capacitances,

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inductances and resistances, its frequency response is unique. Any alteration affecting the rotor winding results in a variation in the equivalent circuit and therefore, in its frequency response [4, 5]. The rotor comprises a shaft that supports a set of wound coils wound on a magnetic core. It can rotate within a magnetic field created either by a magnet or by passing through another set of wound coils on pole pieces, which remain static and constitute the stator of direct or alternating current, depending on the type of machine in question. These machines are subjected to different type of stress, electrical, mechanical, magnetic, and operating environment. They are the factors that can influence the deterioration of insulation and fault, mainly triggered by short circuits between turns or to ground [6]. To ensure the expected life of the machine and maintain its reliability during the operation of the unit, it is required to evaluate the condition of the insulation through a series of test to detect potential problems in the winding. There are two modes in which the series of tests is performed on the SFRA test, first, pole winding and shaft. The second, pole A and pole B. Figure 1 illustrates the SFRA total impedance. The total impedance of an RLC circuit can be calculated using Equation (1).

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad (1)$$

In the test circuit, the source and reference signals are transmitted to the generator rotor coil, and the measurement signal is analyzed on the shaft. Figure 2 shows the setup of an SFRA analyzer at the rotor generator.

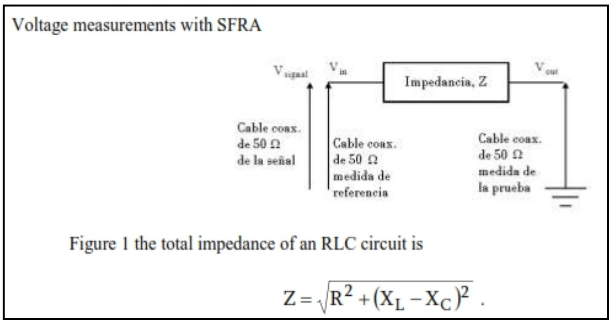

Figure 1. SFRA total impedance.

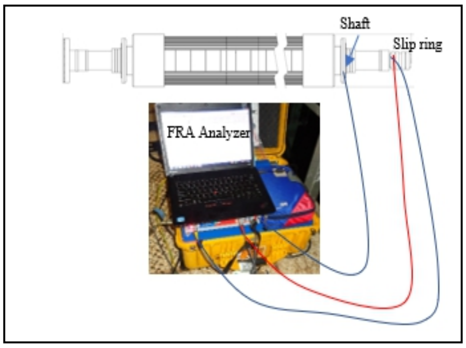

Figure 2. Measurement setup connection of SFRA analyzer at rotor generator.

3. Equipment History

In 2017, the rotor generator was tested and Remaining Life Assessment was conducted. Based on the results in Figure 3, the graphs in do not coincide. Analysis of the Pole A to Shaft and Pole B to Shaft test result shows the deformation and abnormal symptoms in the winding rotor generator. This deformation may indicates short interturn. After inspection and dismantling the rotor generator, short interturn was found during visual check [6]. It is caused by migration insulation interturn end winding and broken insulation between coil layers.

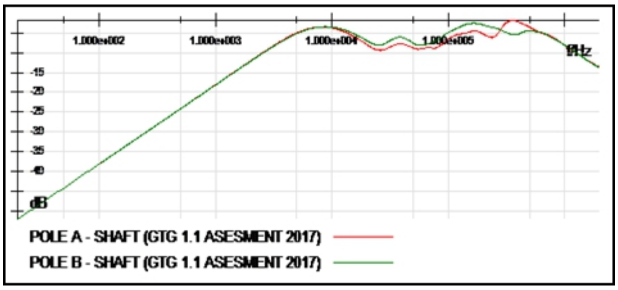

Figure 3. First abnormal condition of SFRA test result in 2017.

As a comparison, a healthy steam turbine rotor generator at the same area was tested with identical time, tools and conditions. The graphs, in Figure 4, coincide, which means there is no defect between the rotor coil and ground.

After 2 years of operation, a maintenance outage was planned for the Gas Turbine Rotor in 2019, for test and repair. The SFRA test result is shown in Figure 5.

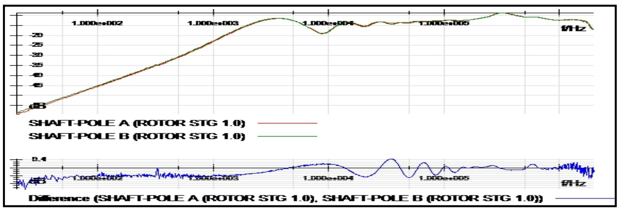

Figure 4. Health winding rotor generator steam turbine STG 1.0 in 2017.

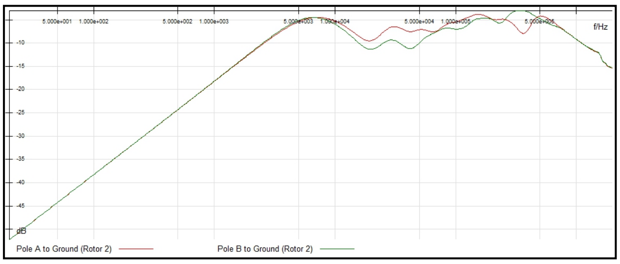

Figure 5. Result of Gas Turbine SFRA Test in 2019 (actual was found short interturn after disassembly).

Figure 6 shows one of the defects found in the generator rotor is a migration of the insulation interturn between the coils which causes a short interturn. The migration occurs at the end winding, especially in the elbow section under the insulation retaining ring.

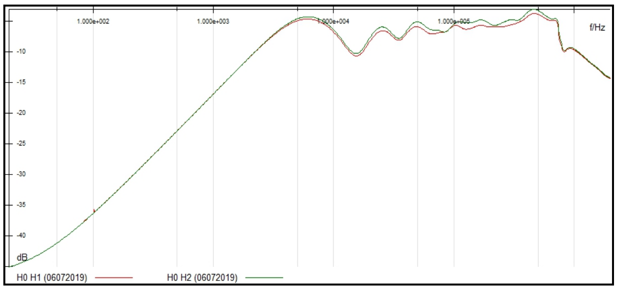

Figure 6. Migration insulation interturn elbow end winding area.

The second type of insulation damage occurs in the coil slot area. Interturn insulation is cut off and perforated due to overheating that occurs while the generator rotor operates. Overheating causes degradation of the insulation interturn layer. This damage can also be detected visually, that is, if the cooling hole in the coil is plugged with an insulation layer, it is possible that the insulation is broken. Figure 7 shows one of the insulation damages in insulation layers coil.

Figure 7. Degradation insulation interturn slot coil.

In different case and type unit of rotor generator, abnormal condition of rotor generator such as elongation coil (irreversible expansion caused by heat coil when generator operation) is possible to happen in rotor winding. Elongation indication can be done by trending every two years. At the steam power plant, there is a trend on the test in the last 2 years, as shown in Figure 8. It can show the normal condition of rotor generator. Based on the results of the visual check and operating data, the generator rotor is in normal condition. So that the test results show that there are no lines that intersect.

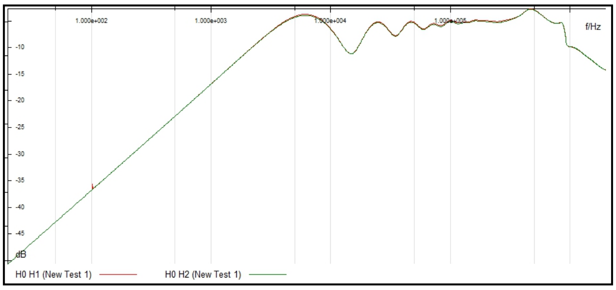

Figure 8. SFRA test result steam power plant in 2016 (normal / health condition).

It was different two years later, after visualizing and comparing the test results, it was found that there were lines that did not intersect. The results of the graph are shown in Figure 9. The graph shows that the trending does not coincide.

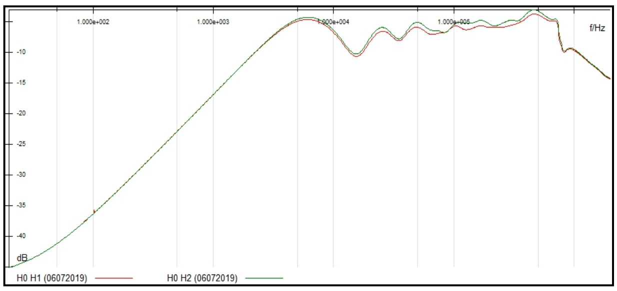

Figure 9. SFRA test result steam power plant after two years operation in 2019 (abnormal condition).

The results of the visual check are shown in Figure 10. Changes in the dimensions of the coil affect the RLC value of the generator rotor winding. The coil damage that occurs in the coil material is an extension of the coil dimensions that does not return to its original shape due to heat from the operation of the generator rotor. This damage can be observed by doing a visual check on the area under the retaining ring.

Figure 10. Visual check coil elongation in 2019.

With an event like this, every winding generator rotor can indicate the existence of an elongation coil

4. Measurement Result

From the three data collection, it can be concluded that the SFRA test can be done as a material for analyzing the condition of insulation on the rotor. Using the last three trending graph data has shown abnormal conditions.

4.1. First Mode Test: A Pole to B Pole, and B Pole to A Pole

The results shown in Figure 11 are from the test on the Turbine Gas Generator rotor at 2017. Using one of the circuit methods, namely by connecting the probe between Pole A to Pole B, no abnormal results were obtained. In this condition the rotor already indicates a short interturn.

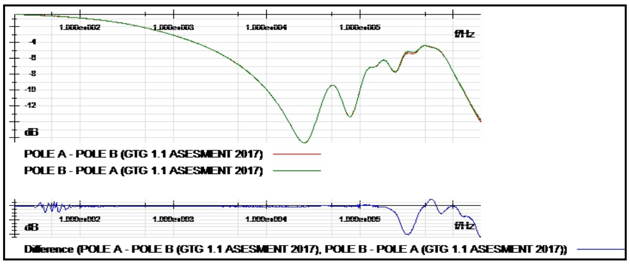

Figure 11. Major Inspection Gas Turbine in 2017

Figure 12 shows the result after two years of operation. The data was collected using the same circuit method (pole A against pole B), which also found no damage. In reality, it has been found that there is a short interturn due to migration of the insulation layer on the end winding and degradation of the insulation slot coil layer.

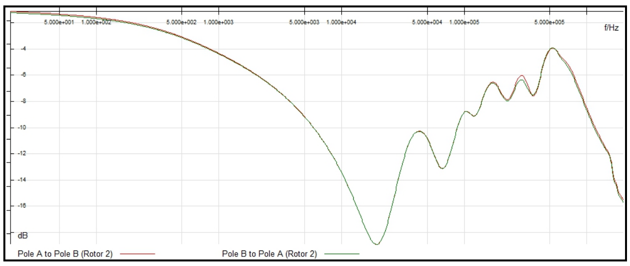

Figure 12. Combustion Inspection Plus Gas Turbine in 2019

Figure 13 shows the test results comparison, tests were carried out at the same time in 2017 on different rotor generator units. The test was carried out on the Steam Turbine Rotor Generator unit. In this case there were no abnormal symptoms either. The generator rotor is in good health.
From the results of the data collection method Pole A to B and Pole B to A, they unable to provide information about the damage to the short insulation interturn. This is because the defect between winding rotor generator is already happened, which there should be an indication of damage from the chart.

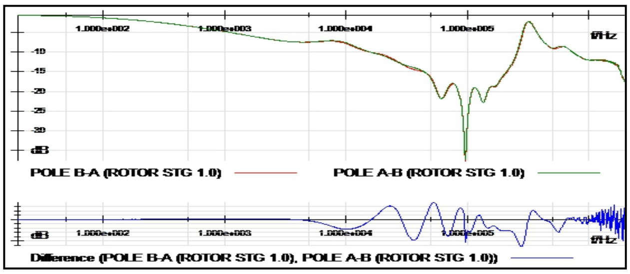

Figure 13. Mean Inspection Steam Turbine in 2019 as a comparison (Health Winding Condition).

4.2 Second Mode Test: A Pole to Shaft, and B Pole to Shaft

The second method to find a short interturn is by connecting the probe circuit between the pole and the shaft. In Figure 14, it is found that there is a graph that does not coincide. This graph shows an abnormal condition in the interturn coil. The results below were carried out in 2017 with an indication of rotor vibration during operation.

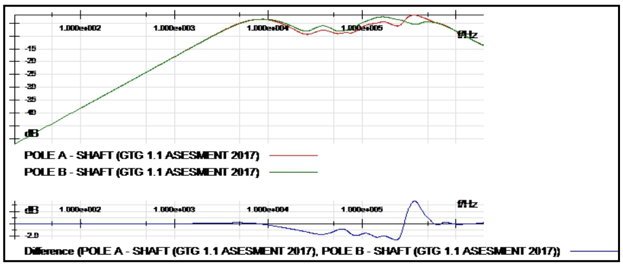

Figure 14. Major Inspection Gas Turbine in 2017.

Figure 15 shows after two years of operating with a vibrating rotor condition, when it was operated with excitation values, the graph was not coincided. This indicates the presence of asymmetry due to changes in resistive and capacitance values.

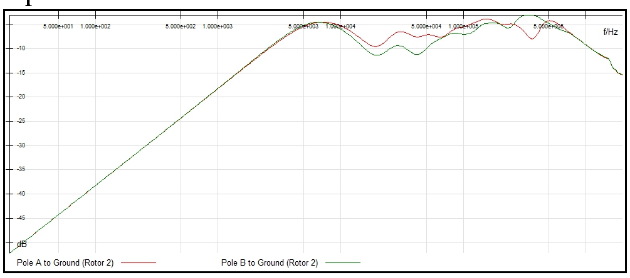

Figure 15. Combustion Inspection Plus Gas Turbine in 2019.

As a comparison that this test method can be accurate, the test is carried out on the generator rotor under normal operating conditions. The graph in Figure 16 shows the absence of normal conditions in the generator by showing a coinciding graph.

Based on the data above the graph in GTG 1.1 does not coincide. So that shows the deformation from the results of the analysis of the Pole A to Shaft and Pole B to Shaft test can show abnormal symptoms on the winding rotor generator. This deformation can also give an indication of short interturn. So, from the 2 mode tests, the test that can be analyzed is the second mode.

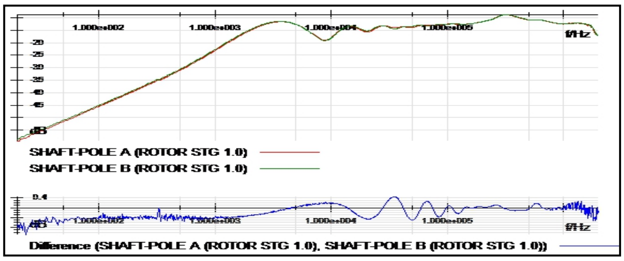

Figure 16. Mean Inspection Steam Turbine at 2019 as a comparison (Health Winding Condition).

4.3 Failure Simulation Rotor Short Interturn Insulation

After dismantling and checking in the Gas Turbine rotor generator. After rotor disassembled and found interturn insulation damage at several layer. Rotor Generator fix to repair with Total Re insulation is performed by replacing interturn isolation between coil layers, insulation slot liner, filler slot wedges, block end winding. With this repair, the generator has returned to health condition. With this health condition a short interturn simulation and several other abnormal conditions can be performed. Figure 17 shows the short interturn simulation graph between 1 layer at coil number 7A. Short interturn simulation graph 3 layers at coil number 4-5A is shown in Figure 18.

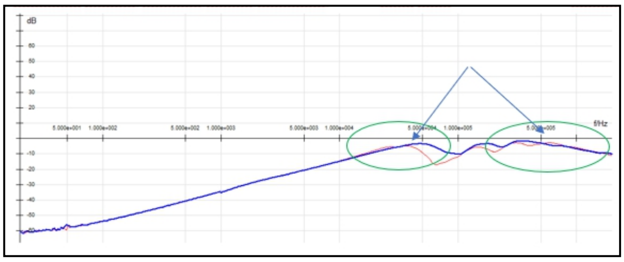

Figure 17. Short interturn simulation graph 1 layer at coil number 7A

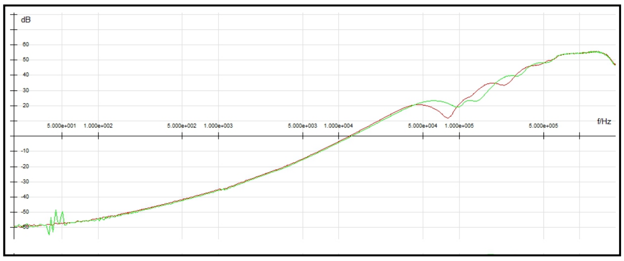

Figure 18. Short interturn simulation graph 3 layers at coil number 4-5A.

4.4 Elongation Coil Simulation

When the generator is operating, expansion occurs. Each winding rotor generator has a different resistivity value. This value will affect the elasticity when the coil expands during operation. Elongation is expansion during operation and the copper coil does not return to the initial dimensions due to different material values and types of copper resistance. Figure 19 shows the elongation simulated result.

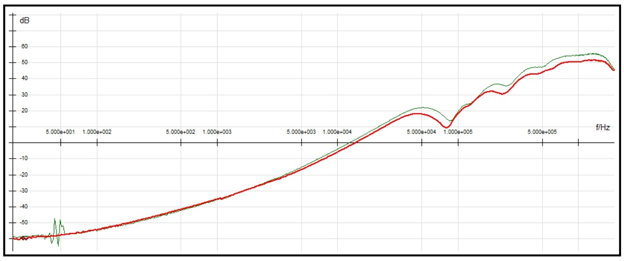

Figure 19. Elongation simulated result.

5. Conclusion

This SFRA test methodology is possible to detect short interturn fault between layer winding, and coil elongation of winding turbo rotor generator, it can identify the problem to find the root cause without major disassembly or dismantling rotor generator. The test method that can show the results of abnormal conditions is the pole to shaft circuit. If any indication coil short interturn, the graphic result showed a cross line, and absolutely coincide. If any indication coil elongation, the graphic result showed a cross line, and without coincide. This tool can be applied as a diagnostic tool of winding rotor turbo generator.

6. References

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